Slide 1

The Mole Concept

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Slide 2

Quantities in Convenient Units

- ✔ We buy beef by the pound, not by the cow
- ✔ We buy eggs by the dozen, not by the each
- ✔ We buy muffins individually, not by the pound
- ✔ We buy spices by the ounce, not by the plant

each

Counting Units

Eggs by the dozen

Spices by the oz

Mass Units

Beef by the pound

In each case, for convenience or size of packaging, we describe the quantity in a unit which is easy to work with. As chemists we do the same thing. We measure quantities either by mass, or by counting units.

Slide 3

The counting units of chemistry

- ✔ Atoms and molecules and formula units are the smallest particles of chemicals. These are our counting units.
- ✔ The larger package that chemists use is called a "mole" and it contains $6.0223(10^{23})$ of the molecules or atoms.
- ✔ Hence 1 mole = $6.0223(10^{23})$ of anything, just as 1 dozen = 12 of anything.
- ✔ The mole is simply a package deal like a "$6.0223(10^{23})$ pack"

Eggs are small, so we group them into a larger package that we call a dozen.

Slide 4

Avogadro's Number, *N*, $6.0223(10^{23})$

- ✔ **One mole of anything contains Avogadro's number of counting units.**
- ✔ **How many molecules of water are there in 2.5 moles of water?**

$$\frac{2.5\text{moles}}{1}\left(\frac{6.0223(10^{23})\text{ molecules}}{1\text{mole}}\right) = 1.5\text{x}10^{24}\text{ molecules}$$

See how the definition: 1 mole=N counting units is used as a conversion factor.

Slide 5

Mole Conversions

Calculate the formula units of Na_2CO_3 in 1.29 moles of Na_2CO_3

See how the definition: 1 mole=N counting units is used as a conversion factor.

Slide 6

Mole Conversions

Calculate the number of moles of copper in $3.55\ x10^{22}$ atoms of copper

See how the definition: 1 mole=N counting units is used as a conversion factor.

Slide 7

Mole Conversions

Calculate the number of moles of sodium in 2.53 moles of sodium carbonate.

Note the number of sodium atoms in each formula unit.

Slide 8

Mole Conversions

Calculate the number of atoms of sodium in 2.53 moles of sodium carbonate.

This is just one more step! Convert moles of atoms to atoms.

Slide 9

The mass units of chemistry

- **When we measure large quantities of a substance, we use the large mass unit (g)**
- **One gram is a mole of atomic mass units:**

$6.0223(10^{23})$amu=1g

- **What mass in amu is 10.5 g?**

$$\frac{10.5\text{g}}{1}\left(\frac{6.0223(10^{23})\text{ amu}}{\text{g}}\right) = 6.32\text{x}10^{24}\text{amu}$$

As we discussed, atoms and molecules are tiny and have very small masses. We measure individual atoms and molecules using tiny atomic mass units (a.m.u.)
See again how the definition of a g is used as a conversion factor.

Slide 10

Relating mass to counting units

- ✔ When we buy sugar, it is easier to mass it than to count the crystals. We have created a relationship between the amount of sugar (number of crystals) and the mass. 1 bag sugar=5 lb sugar
- ✔ Other packages may contain different quantities. For example 1 pkg butter = 1 lb butter.

Slide 11

Relating mass to a substance

- ✔ Atoms have a specific mass associated with them, shown on the periodic table.

  1 atom C = 12.011 amu Carbon
- ✔ Molecules also have a mass associated with them, that we call the “molecular mass “or “formula mass”.

Slide 12

Calculating Formula Mass

- ✔ We obtain the molecular mass by summing the contributions of all atoms in the molecule.
- ✔ For example, CO_2 contains 1 carbon atom and 2 oxygen atoms so the molecular mass is:

1(12.011amu) + 2(15.9994amu) =44.0098 amu

Slide 13

Calculate the formula mass expected for each of the following:

NaCl

H_2O

Na_3PO_4

$Ca_3(PO_4)_2$

Slide 14

Molar Mass

- **Since we rarely use one molecule of a compound, it would be more convenient to describe the mass of an entire mole of it ($6.0223(10^{23})$) formula units or molecules).**
- **Such a mass is termed the molar mass and its value is the same as the formula mass. Its units, however, are the larger units of grams.**

Note that the numerical value is the same- the units alone differ.
for example: (22 amu/particle)(**N** particles/mol)(1g/**N** amu) = 22 g/mol

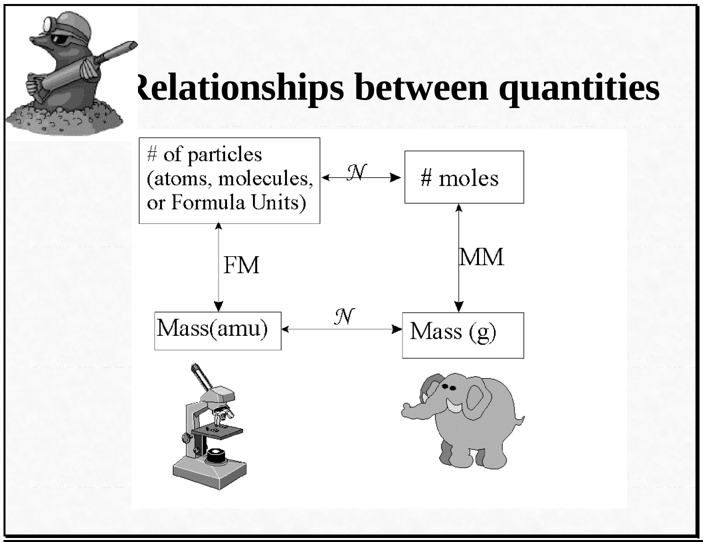
Slide 15

Molar Mass of Practice compounds

- **MM NaCl = 64.443 g**
- **MM H_2O= 18.01528 g**
- **MM $Na_3(PO_4)$= 163.94071 g**
- **MM $Ca_3(PO_4)_2$ = 310.1828 g**

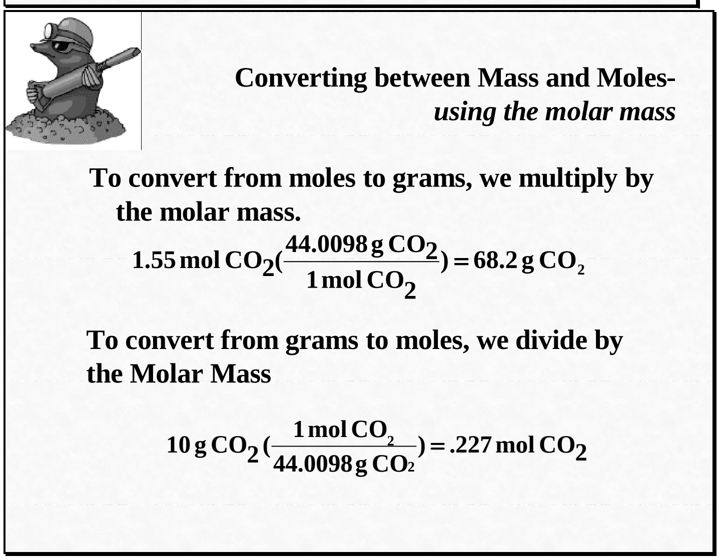
Note that 1 Molar quantities are expressed in large units(g). Formula or molecular quantities are expressed in small units (amu)

Slide 16



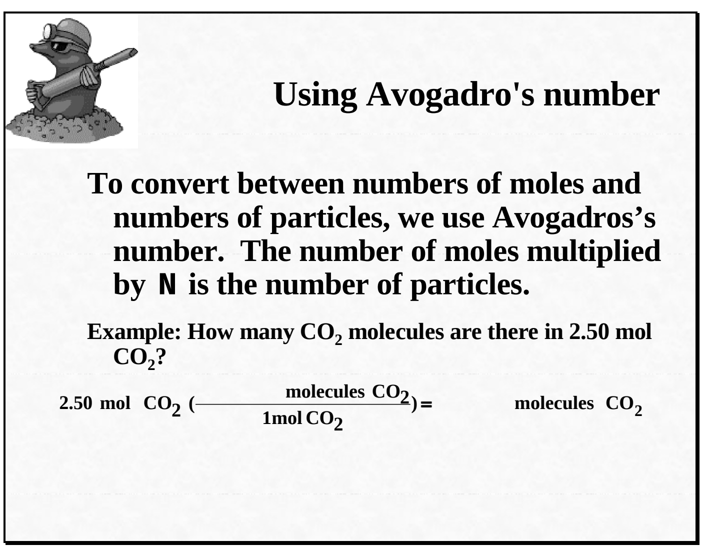
1mole = N counting units (particles)
1mole=MMg
1g=N amu
1counting unit = FM amu

Slide 17



1mole CO_2 has a molar mass of about 44 g. Thus, a conversion factor may be written: 44.0098 g CO_2=1 mol CO_2.
Thus to find how many moles of CO_2 are in 10 g of CO_2, we divide the mass by the molar mass.
Again, the definition of a mole, with respect to the molar mass is used as a conversion factor.

Slide 18



It takes many small particles to make a mole, avogadro's number (N) in fact. Thus a conversion factor can be written:
$6.0232(10^{23})$ particles=1 mole
the particles might be atoms or molecules or even tires- this is a definition of a packaging quantity.

Slide 19

Using Avogadro's Number

The number of particles divided by N is the number of moles.

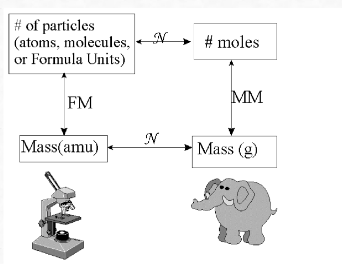
Example: Calculate the number of moles of CO_2 that $2.0x10^{23}$ molecules of CO_2 represent.

$$2.0(10^{25})\text{ molecules } CO_2 \left(\frac{1\text{mol } CO_2}{\quad CO_2}\right) = \qquad \text{mol } CO_2$$

Slide 20

Look back at the relationship diagram:

How would you convert between the number of molecules and the mass in amu?

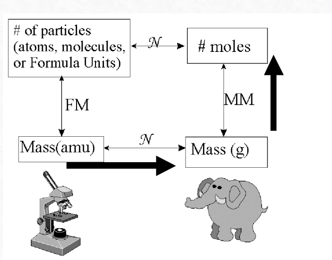


The relationship between number of molecules (counting units) and amu is the formula or molecular mass.
1 counting unit = FM amu

Slide 21

Know the relationships!

There is no direct conversion between some of the quantities. For example, converting from amu to moles requires 2 conversions.



Can you find the other pathway?

Note that amu relates directly to g and to particles. This must be a 2-conversion problem.
The path used to reach the answer is not important. (Commutative Law of Multiplication)

Slide 22

Know the relationships!

Example: Calculate the number of moles of CO_2 that 2.0×10^{23} amu of CO_2 represent.

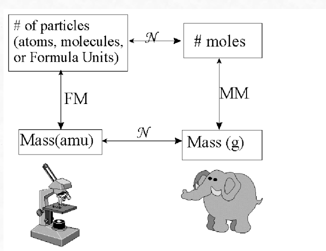
Or

Note that amu relates directly to g and to particles. This must be a 2-conversion problem.
The path used to reach the answer is not important. (Commutative Law of Multiplication)

Slide 23

Let's Try another……

Example: Calculate the number of g of CO_2 that 2.0×10^{23} molecules of CO_2 represent.



One pathway

Or the other pathway

Slide 24

Let's Try another……

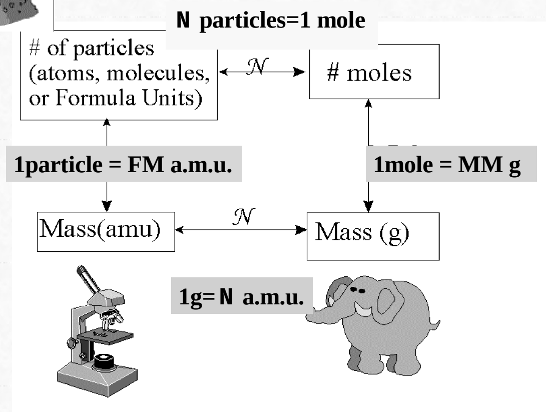
Example: Calculate the number of g of CO_2 that 2.0×10^{23} molecules of CO_2 represent.

Or

Note that amu relates directly to g and to particles. This must be a 2-conversion problem.
The path used to reach the answer is not important. (Commutative Law of Multiplication)

Slide 25

Summary: 4 conversion factors



Remember that the FM is unique to the substance observed, but **N** is not.

Slide 26

Percent Composition

✔**Percent composition is a list of the mass percent of each element in a compound.**

Na_2CO_3 is

- **43.38% Na**
- **11.33% C**
- **45.29% O**

What is the sum of the percent composition of a compound?

Slide 27

Percent Composition

How is it calculated?

✔**Determine the molar mass of the compound.**

2(22.9898gNa) + 1(12.011gC) + 3(15.9994 gO) = 105.9887g Na_2CO_3

✔**Find ratio of mass of element to mass of compound.**

$$\frac{2*22.9898\,\text{g Na}}{105.9887\,\text{g}\ \ Na_2CO_3} x100\% = 43.38\%\text{Na}$$

Round the percents to two decimal places.

Slide 28

Percent Composition

Calculate the %Comp of $Ca(NO_3)_2$

- ✔ **Determine the molar mass of the compound.**
- ✔ **Find ratio of mass of element to mass of compound.**

Slide 29

mpirical vs Molecular Formulas

glucose

$C_6H_{12}O_6$

- ✔ **The molecular formula for a substance is the actual ratio of atoms in the substance.**
- ✔ **The empirical formula is the *lowest whole number ratio* of atoms in a compound.**
- ✔ **Note that the molecular formula is a whole number multiple of the empirical formula.**

Ionic compounds are always written in empirical form, but molecular compounds are not.

Slide 30

Determining the multiplier, n

The ratio of the molecular mass to the mass predicted by the empirical formula tells us how many times larger the molecular formula is.

$$n = \frac{\text{molecular formula mass}}{\text{empirical formula mass}}$$

Glucose $$n = \frac{180.1572\text{ g } C_6H_{12}O_6}{30.0262\text{ g } CH_2O} =$$

Slide 31

Determining the Molecular Formula

Determine the molecular formula of a nitrogen oxide compound (N_xO_y) with a molar mass of 92.011 g and a empirical formula of NO_2.

Slide 32

Determining Empirical Formula

Organize your information in a Table:

	Component	Element A	Element B	Element C
Assume 100 g of compound	Mass (g)			
	MM (g/mol)	MM of A	MM of B	MM of C
Convert to Moles	Moles			
Find mol ratio	Divide by the smallest number of moles			
	Round or reduce fractions			

Slide 33

A substance is known to be 35.00% N, 5.05% H and 59.96% O. What is its EF?

	Component			
Assume 100 g of compound	Mass (g)			
	MM (g/mol)			
Convert to Moles	Moles			
	Divide by the smallest number of moles			
Find mol ratio	Round or reduce fractions			

Assuming 100 g sample, there would be 35.00g N, 5.05 g H and 59.96 g O.

Slide 34

Common ratios and their decimal equivalents

decimal	multiplier	ratio
1.25	4	5/4
1.3333	3	4/3
1.50	2	3/2

For example:

Slide 35

etermine the Molecular Formula of $N_2H_4O_3$ if the MM of the compound is 80.06 g/mol.

- ✔ **The ratio that we obtained was $N_2H_4O_3$, and this is the empirical formula**
- ✔ **To determine the MF, we need to find the ratio of the known Molecular mass to that of the Empirical Formula.**

Slide 36

Practice Problem:

A disinfectant is known to be 76.57% C , 6.43% H, and 17.00% O. Determine its empirical formula.

Slide 37

Solution

	Component			
Assume 100 g of compound	Mass (g)			
Convert to Moles	MM (g/mol)			
	Moles			
Find mol ratio	Divide by the smallest number of moles			
	Round or reduce fractions			